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RADIATION DIRECTIVITY PATTERN OF A SEMICONDUCTING MULTILAYER STRUCTURE

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In view of their small thickness and of the optical inhomogeneity of the active layer, semiconductor lasers with one p-n junction have in the typical case a directivity pattern with an aperture angle at half-intensity of about 15° in the plane perpendicular to the p-n junction plane, and of several degrees in the junction plane. In [1] are described certain characteristics of an injection GaAs laser with a multilayer structure of the p-n-p-n-p-n type, obtained epitaxially from the gas phase using arsenic hydride.

We demonstrate in this communication the possibility of narrowing down the directivity pattern in a plane perpendicular to the p-n junction plane as a result of greatly broadening the active region using a multilayer structure. In our case we used an open-tube chloride epitaxial procedure [2] modified in such a way as to ensure the production of GaAs layers with a controllable degree of compensation with an acceptor impurity. Multilayer structures were obtained by a single process on n-GaAs substrates oriented with accuracy 1 - 3' in the {100} plane.

An example of such a structure is shown in Fig. 1. Four thin (~0.7 μ) layers (p-n-p-n) are located between thick layers of n- and p-type in the lower and upper parts of the plate, respectively. The entire region of the multilayer structure is uniformly doped by an amphoteric impurity (Sn). The electron density in the n-type layers amounts to about 2×10^{18} cm^{-3}. The p-type layers (dark in Fig. 1) were obtained by overcompensation with an acceptor impurity (Zn) and have a hole density of about 7×10^{19} cm^{-3}.

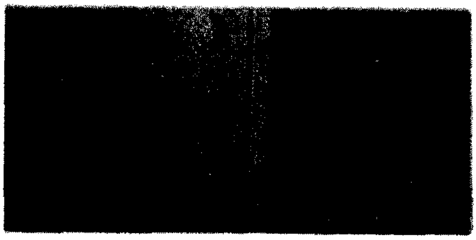

Fig. 1. Multilayer structure of the p-n-p-n-p-n type.

A Fabry-Perot interferometer with L = 0.35 cm was obtained by cleaving a plate with ohmic contacts along the cleavage planes. For the investigation, the crystals, measuring 0.35 × 0.25 × 0.12 mm, were placed in a clamp holder.

When the laser with multilayer structure is immersed in liquid nitrogen and is excited with rectangular current pulses with τ_0 = 2 μsec and f = 200 Hz, the density of the generation threshold current is $I_{\rm thr}$ = 10 - 20 kA/cm^2.

The laser directivity pattern was investigated with the aid of a photomultiplier with a diaphragm placed in front of its photocathode. The linearity of the signal from the photomultiplier was ensured by using calibrated neutral filters. The angular resolution in the measurement of the directivity pattern is 20'.

At a small excess above the threshold current, a sharp maximum in the plane perpendicular to the junction plane is observed against the background of the three-dimensional distribution of the radiation. The direction of the maximum is inclined approximately 15° to the normal to the radiating surface, in the direction of the negative electrode (Figs. 2a, b). With further increase of the current, the divergence of the radiation in the direction of this maximum decreases, and amounts to 2.5° at half-intensity when $j = 2j_{thr}$ (Fig. 2c). As seen from Fig. 2c, the entire laser radiation in the plane perpendicular to the junctions is concentrated in a small angle. The spectrum of the directional radiation beam at pump-current pulse duration 100 nsec has in the region of $\lambda \approx 8430$ Å a band analogous to the emission band of a laser with one p-n junction, and also an additional band with $\lambda \approx 8360$ Å (Fig. 3), thus offering evidence of the presence of generation in the n-regions of the multilayer structure. The threshold of the occurrence of the long-wave band is somewhat lower than for the short-wave band. With increasing pulse duration or pulse repetition frequency, the short-wave band disappears, obviously because of the heating of the active region. The long-wave radiation is practically unpolarized, whereas the short-wave radiation is partly polarized.

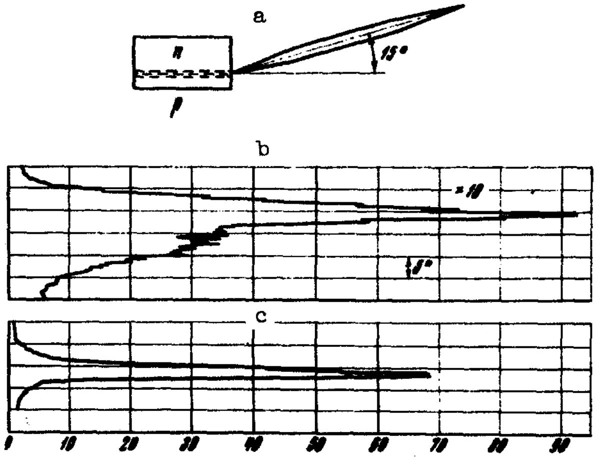

Fig. 2. Directivity pattern of radiation of a multilayer laser in a plane perpendicular to the planes of the p-n junctions: a - schematic representation; b - at a slight excess over j_{thr}; c - at $j = 2j_{thr}$.

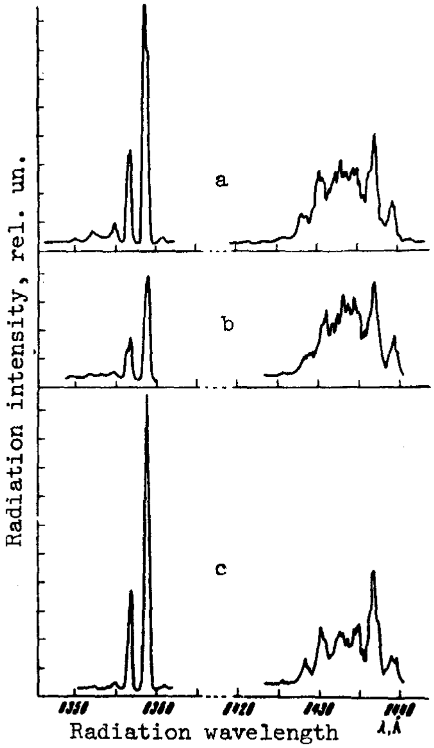

Fig. 3. Emission spectra of a laser with a multilayer structure: a - without a polaroid filter; b - polaroid polarization plane perpendicular to the p-n junction planes; c - polaroid polarization plane parallel to the p-n junction planes.

The deviation of the radiation beam from the normal to the mirror face of the Fabry-Perot resonator is due to the optical asymmetry of the active region. The presence of a large gradient of the refractive index in a direction perpendicular to the plane of the p-n junctions is due to the gradient of the distribution of the injected carriers [3, 4]. As a result, the front of the wave corresponding to a constant phase difference is not parallel to the emitting surface of the laser.

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FINE STRUCTURE OF THE DISTRIBUTION FUNCTION OF AN ELECTRON BEAM INTERACTING WITH A PLASMA

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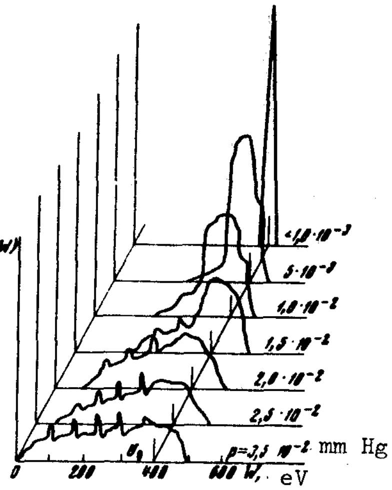
Most reported [1 -3 and others] measurements of the distribution function of an electron beam interacting with a plasma were made by the decelerating-field method, which is known to have low resolution. We have used in the present investigation for the analysis of the energies a cylindrical capacitor with a resolution of about 1%, as a result of which we were able to observe the fine structure of the distribution function against the background of the produced plateau.

The investigations were carried out with an electron beam of 5 mm diameter, and a current 10 - 20 mA; the accelerating voltage could be varied from 300 to 1200 V. The measurements were performed without a magnetic field. The electron beam passed along the axis of a glass tube of 35 mm diameter and 300 mm length, filled with hydrogen at $p = 10^{-4} - 5 \times 10^{-2}$ mm Hg. The plasma was produced by the beam itself (beam plasma); the plasma parameters could be measured with Langmuir probes; the microwave oscillations were detected with a helix introduced inside the tube.

The electrons, after passing through the plasma, entered the cylindrical capacitor through an opening of 1.5 mm diameter drilled at the center of the electron collector. The volume in which the capacitor was located was evacuated to 10^{-5} mm Hg.

A typical family of distribution functions, with the gas pressure as the parameter, is shown in the figure. The curves show clearly the plateau-formation dynamics described in [4]. At the same time, a number of periodically spaced peaks forming the fine structure of the distribution functions can be seen against the background of the plateau. These peaks appear at $p \geq 1.5 \times 10^{-2}$ mm Hg and develop further with increasing pressure. The average interval between them is about 50 - 100 V.

The energy corresponding to the fine-structure peaks varies little with changing gas pressure. On the other hand, if the parameter of the family is the beam current i or the accelerating voltage U_0, then the position of the peaks shifts toward higher energies with increasing U_0 or i.



Family of measured energy distribution functions of the beam electrons. The parameter of the curves is the gas pressure. $U_0 = 400$ V, i = 8 mA.

The fine structure is seen quite distinctly on the distribution function. However, on the delay-current curve, which we could obtain either experimentally by the decelerating-field method